

# “SimVal” – A High-Pressure Optically Accessible Combustor for Simulation Validation



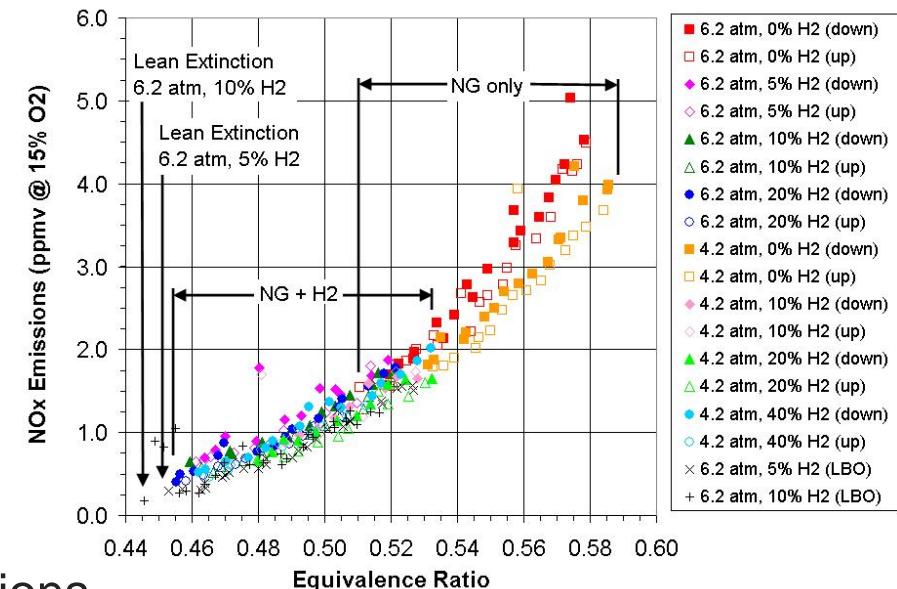
Pete Strakey

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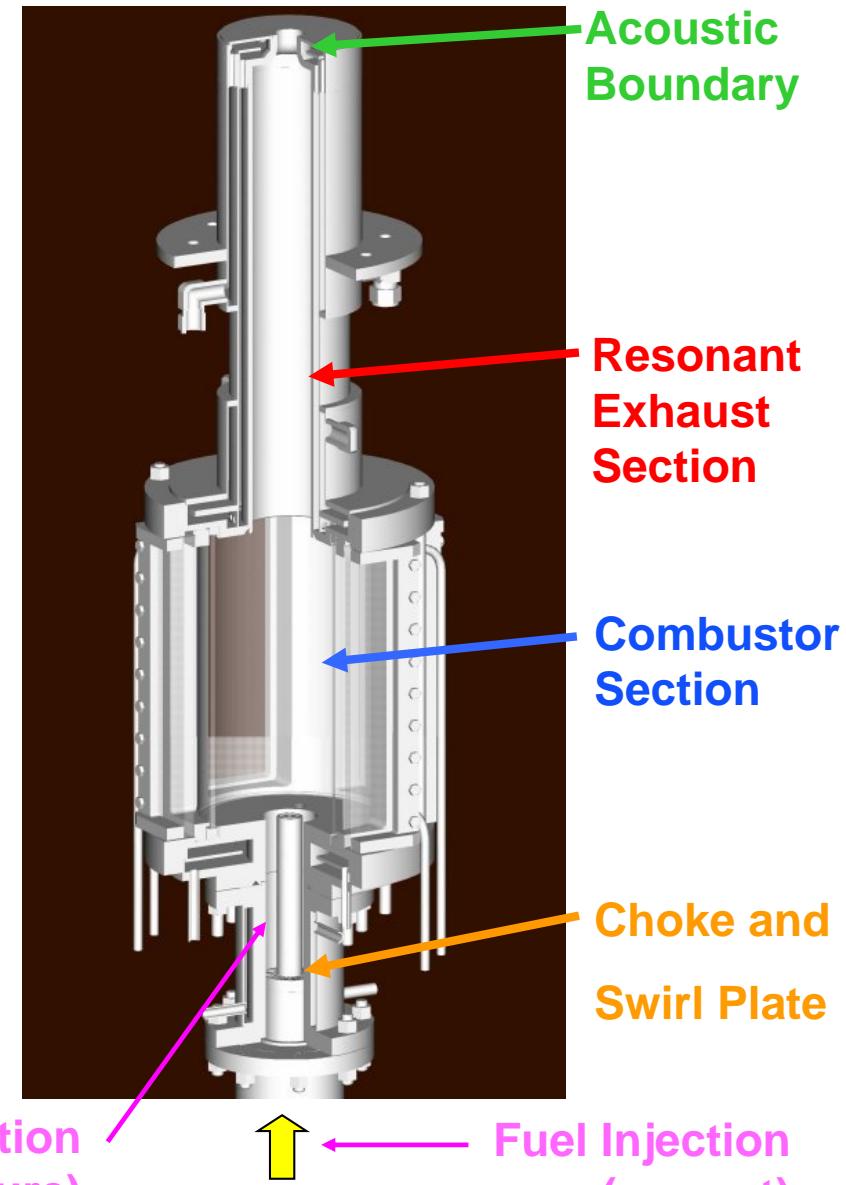
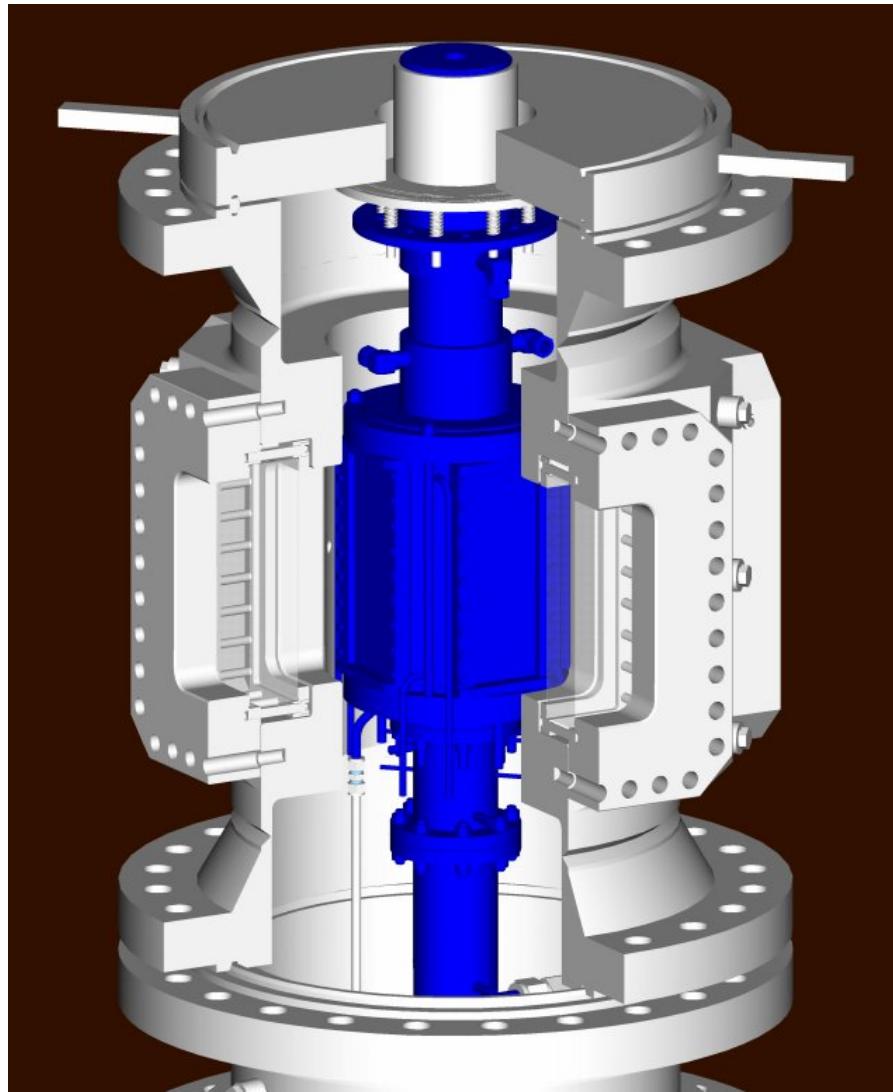
**10<sup>th</sup> International Workshop on  
Premixed Turbulent Flames**  
**August 12-13, 2006**  
**Mainz, Germany**

# SimVal Project Goals

- Provide data sets for the validation of CFD (LES) simulations to aid the development of advanced gas turbine combustors
  - Gather data at elevated combustor pressures
  - Emissions
  - Dynamic modes and pressures
  - Flow field characterization
  - Boundary condition characterization
  - Dynamic events and transitions
    - Lean Blow-Off
    - Flashback
    - Abrupt changes in dynamics and emissions
  - Effects of fuel variability on emissions, dynamics, lean blow-off, and flashback.

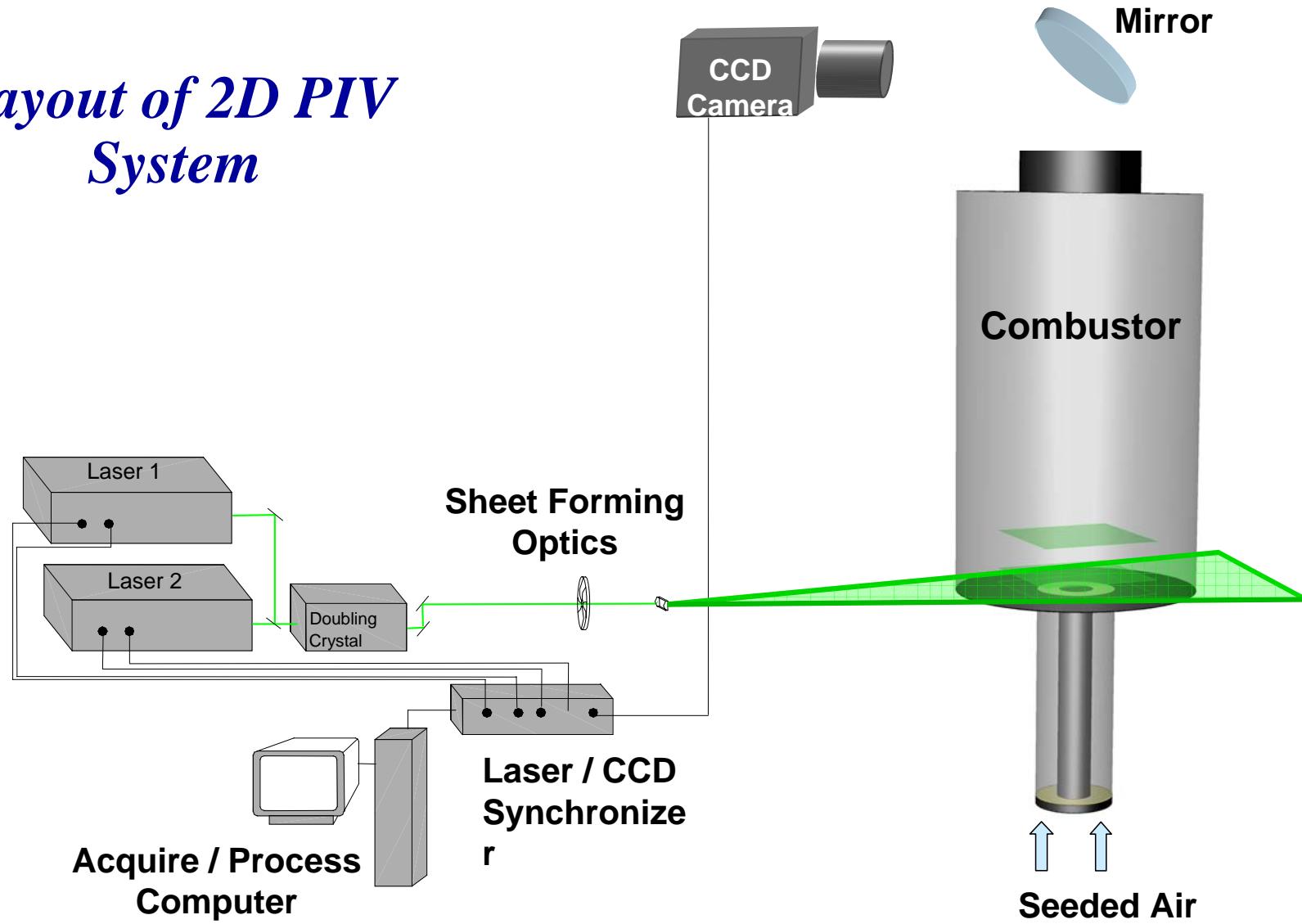


# SimVal Premixed Combustor Geometry



# SimVal PIV Cold Flow Study

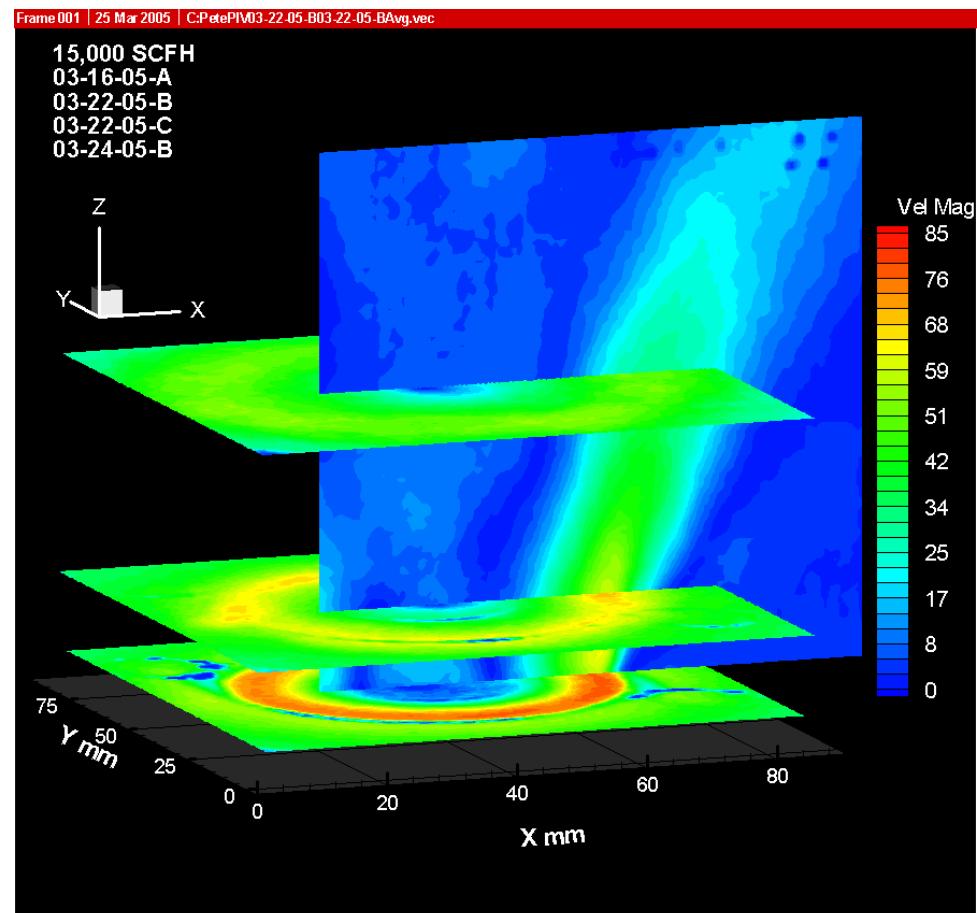
## *Layout of 2D PIV System*



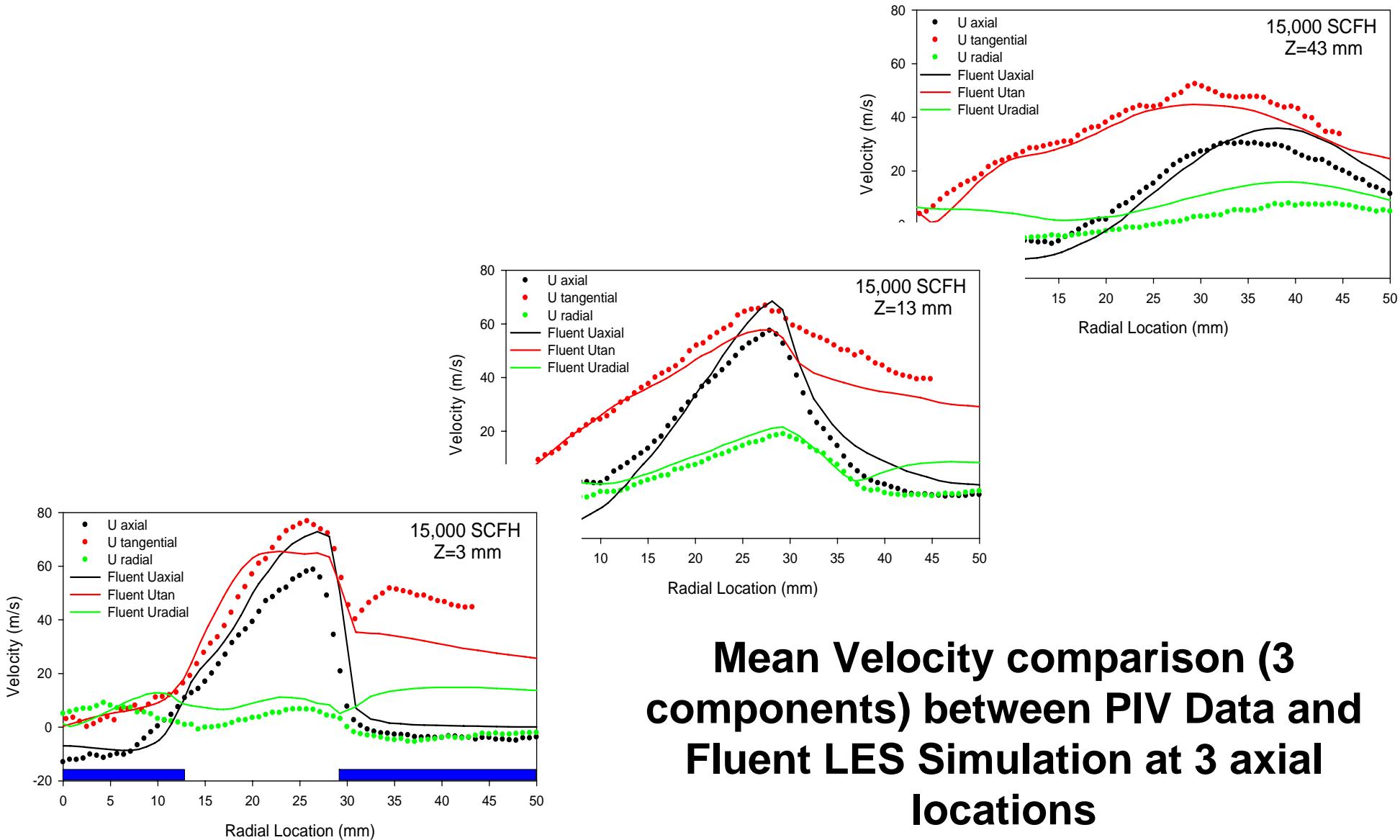
# PIV Data Summary

- Good data-sets at 1500 and 15,000 SCFH
  - Vertical centerline slices ( $U_z$  &  $U_r$  200 shots each)
  - 3 horizontal slices ( $U_\theta$  &  $U_r$  100 shots each)

Each Plane  
F.O.V. ~ 90 mm  
3900 vectors  
 $1.4 \times 1.4 \times 1.1$  mm  
Mean  $U_x$  &  $U_y$   
RMS  $U_x$  &  $U_y$   
Vorticity  
Re Stress  
Strain Rate  
Etc...



# PIV Comparison to LES Studies



**Mean Velocity comparison (3 components) between PIV Data and Fluent LES Simulation at 3 axial locations**

# OH PLIF System Layout

Laser Excitation Wavelength ~ 283.92 nm

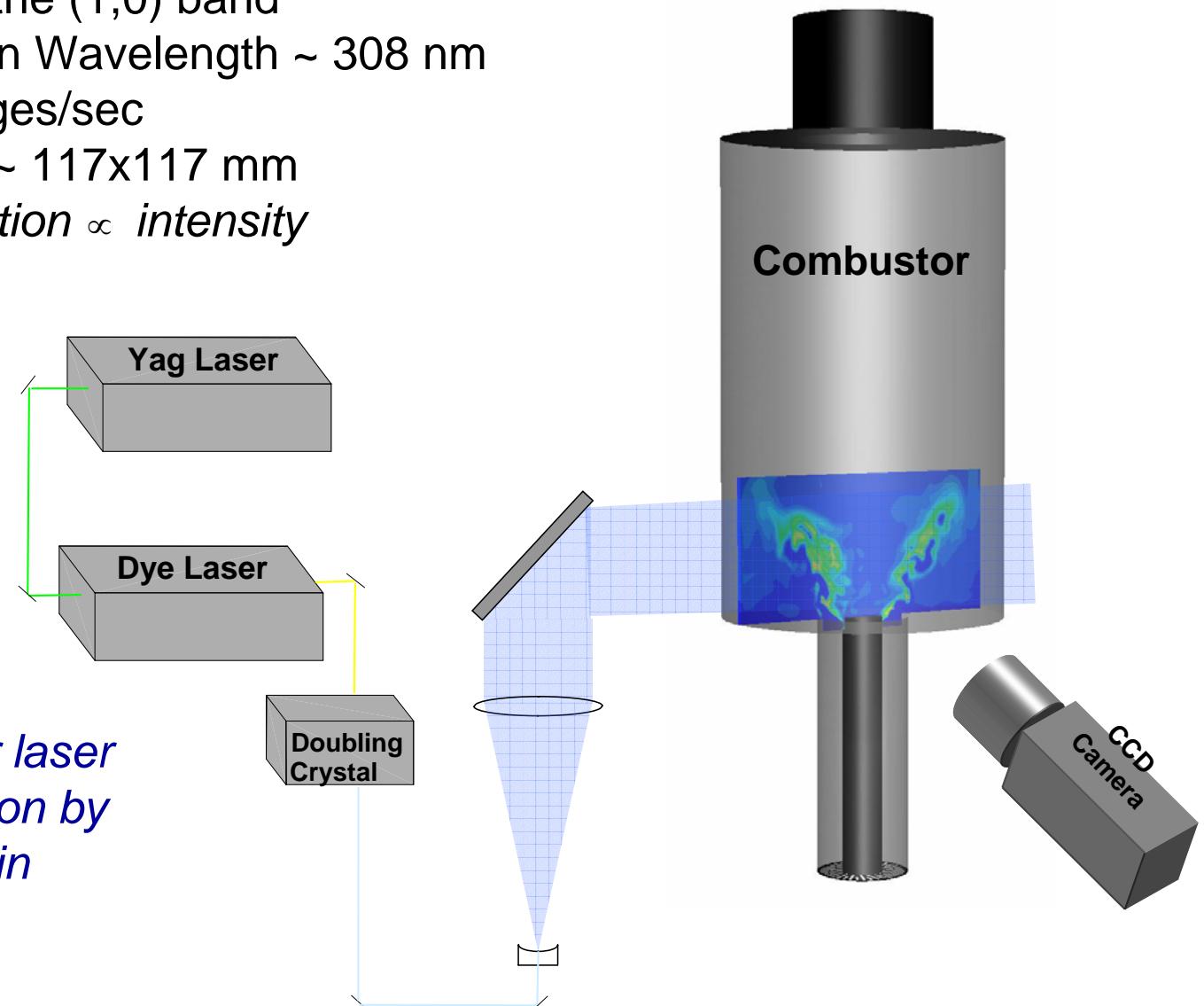
Q1(8) line of the (1,0) band

Fluorescence Collection Wavelength ~ 308 nm

2 images/sec

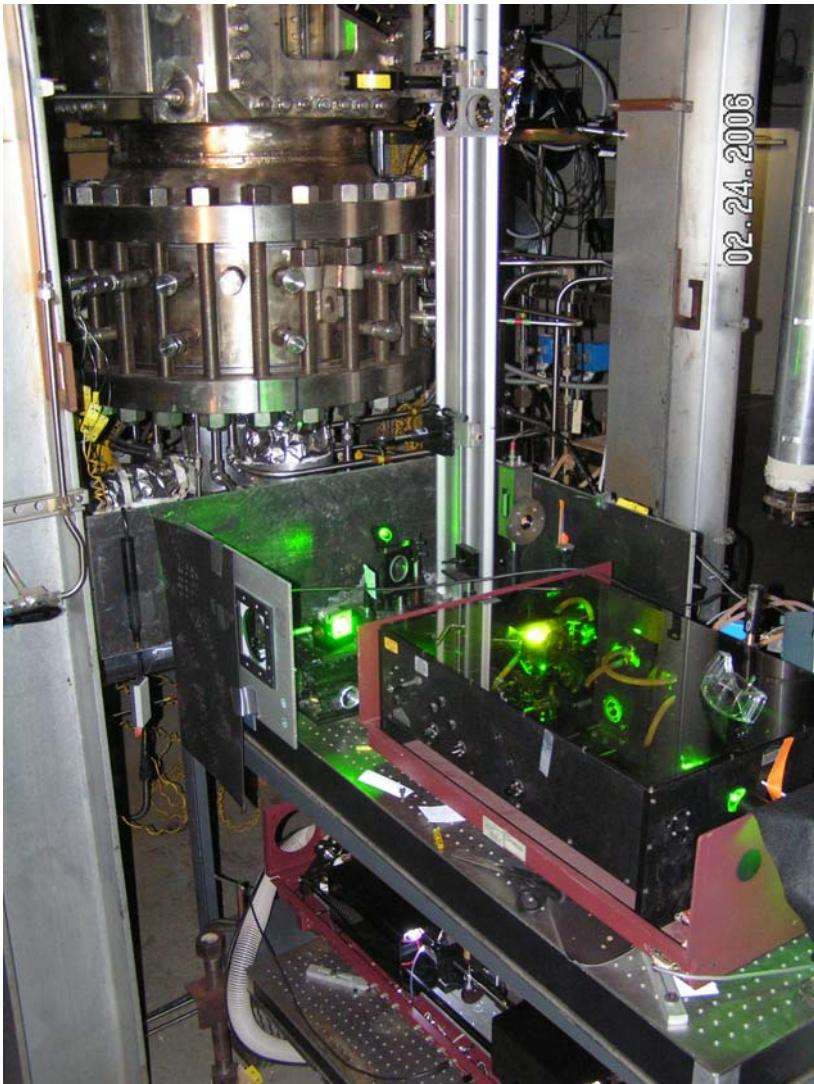
Field-of-view ~ 117x117 mm

*OH concentration  $\propto$  intensity*



*All images corrected for laser sheet intensity distribution by imaging acetone vapor in combustor.*

# OH PLIF Test Conditions



***Two fuel compositions  
were studied***

## **100% Natural Gas**

Tin ~ 550K  $\Phi=0.6$

P=1,2,4 and 8 atm

$T_{ad}=1850K$

SL= 63 cm/s @ 1atm

## **40% Natural Gas / 60% H<sub>2</sub>**

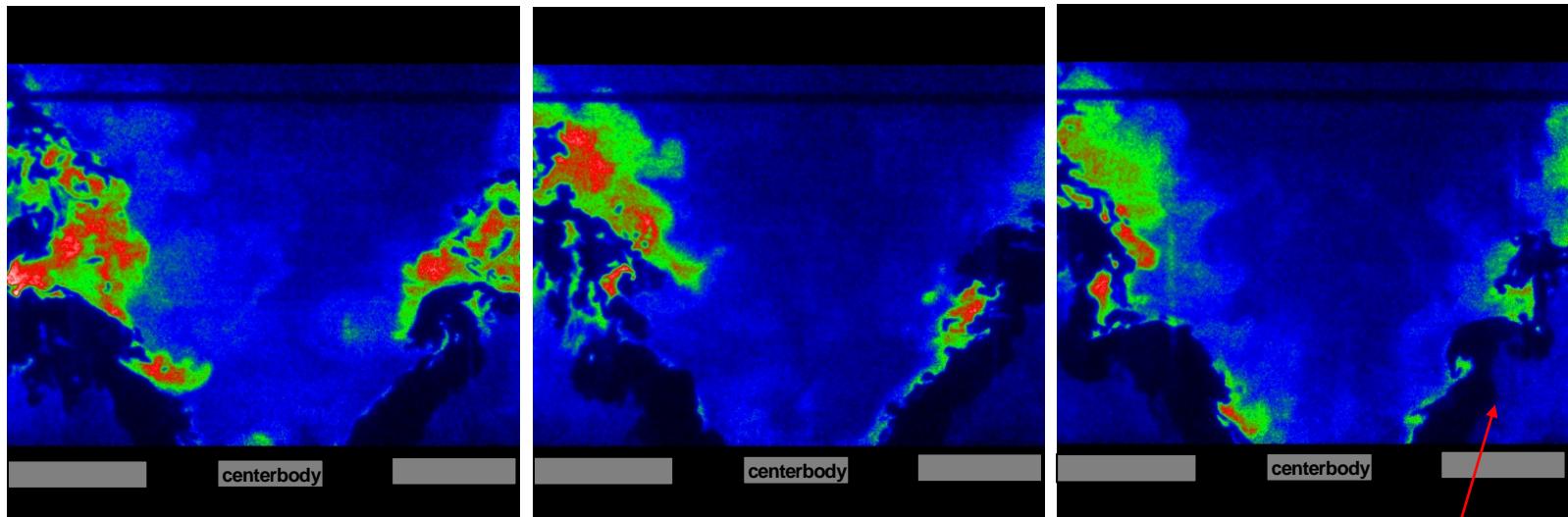
Tin ~ 550K  $\Phi=0.6$

P=1,2, 4 and 8 atm

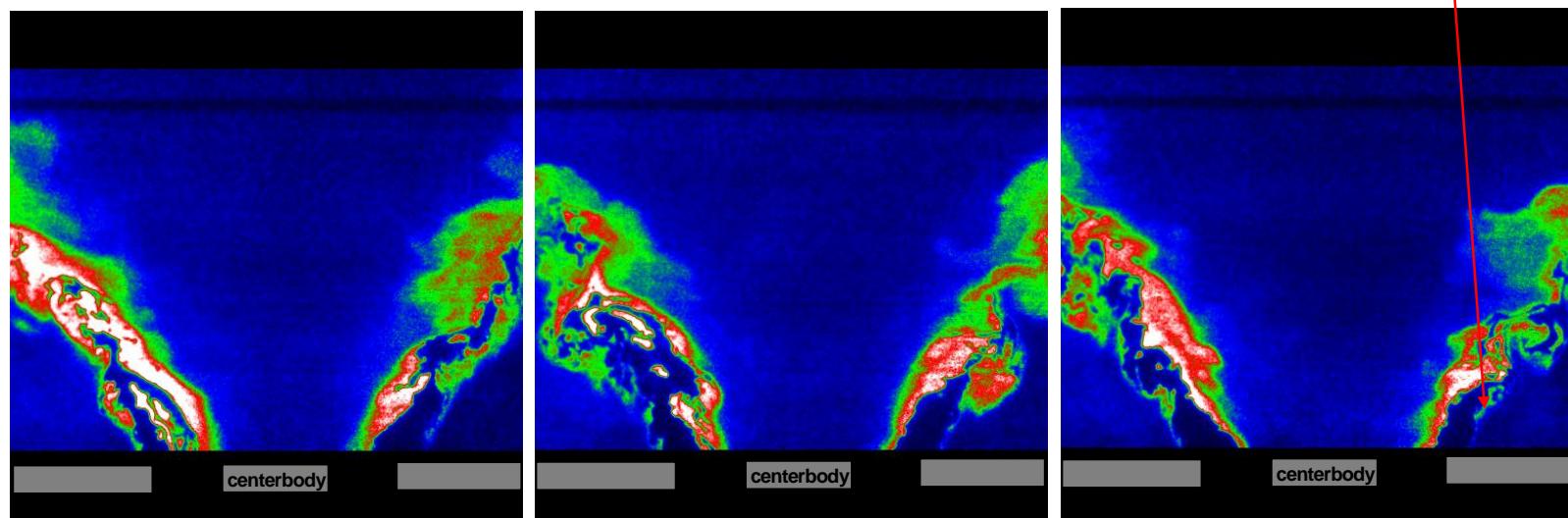
$T_{ad}=1900K$

S<sub>L</sub>=99 cm/s @ 1 atm

# Effect of Hydrogen (P=1 atm, instantaneous snapshots)

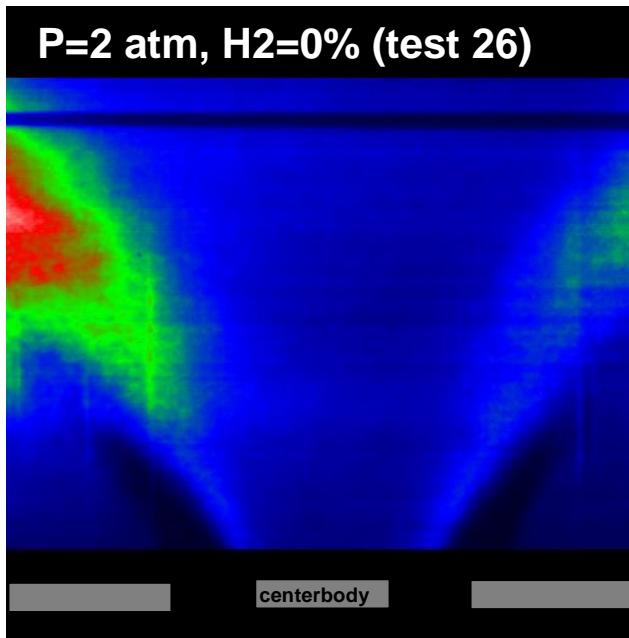


- Adding  $H_2$  increases combustion on outer edge of flame
- Increased kinetics overcomes heat losses

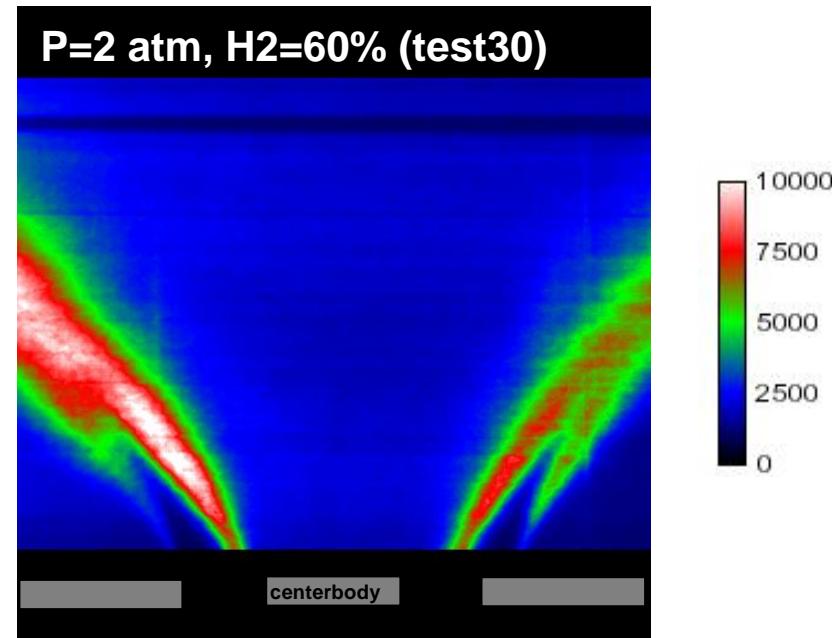


# Effect of Hydrogen (Average Images)

- Combustion region moves upstream with hydrogen addition due to faster reaction kinetics.



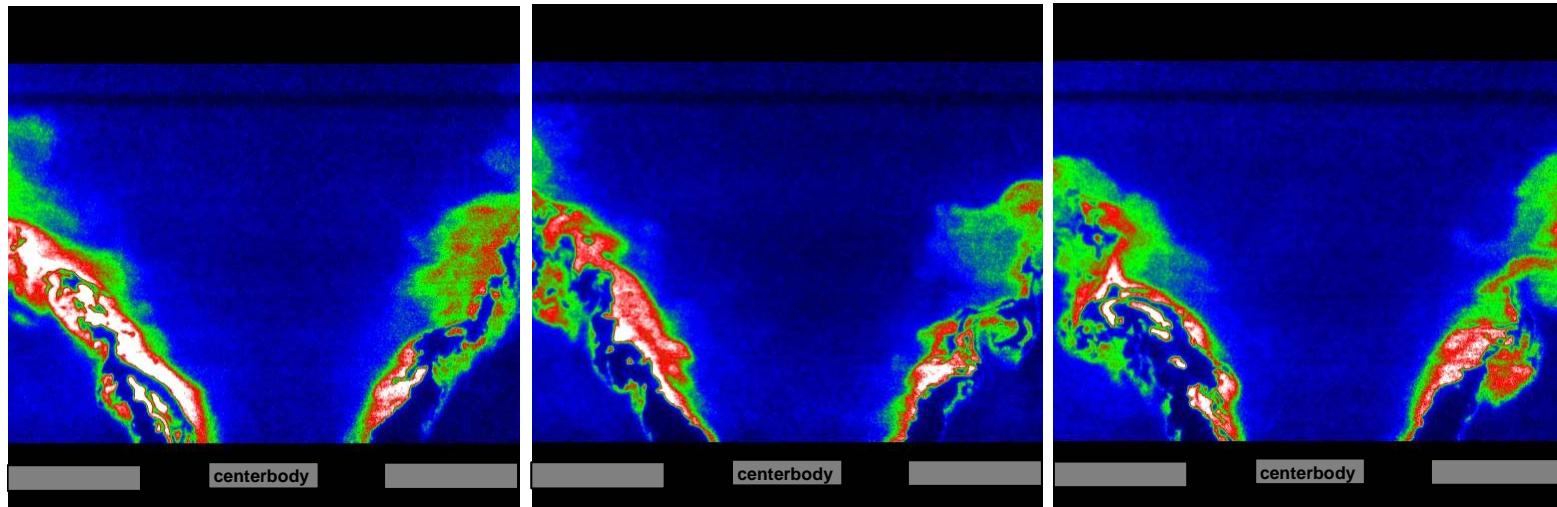
0% H<sub>2</sub> / 100% NG  
 $\Phi=0.6$   
 $T_{in}= 522-580K$   
 $V=40 m/s$



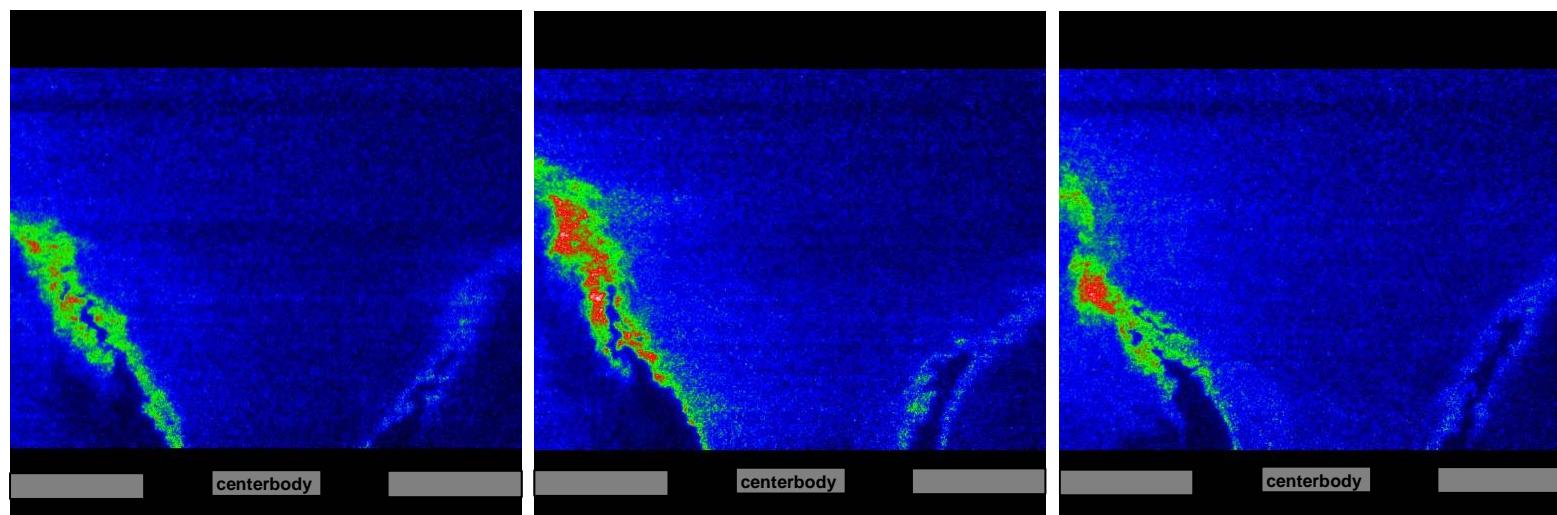
60% H<sub>2</sub> / 40% NG  
 $\Phi=0.6$   
 $T_{in}= 522-580K$   
 $V=40 m/s$

# Effect of Pressure (Instantaneous Snapshots)

60% H<sub>2</sub> / 40% NG  $\Phi=0.6$   $T_{in}= 522-580K$   $V=40$  m/s



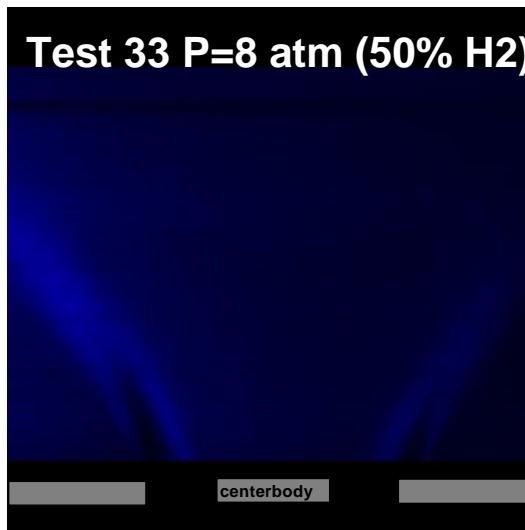
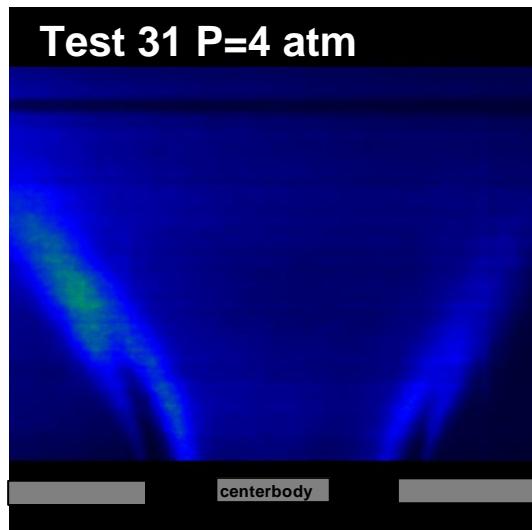
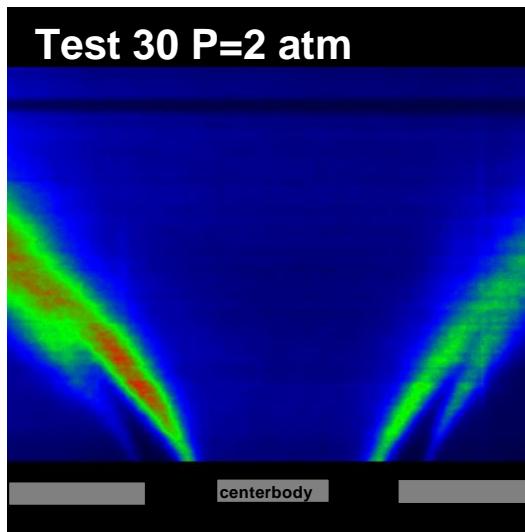
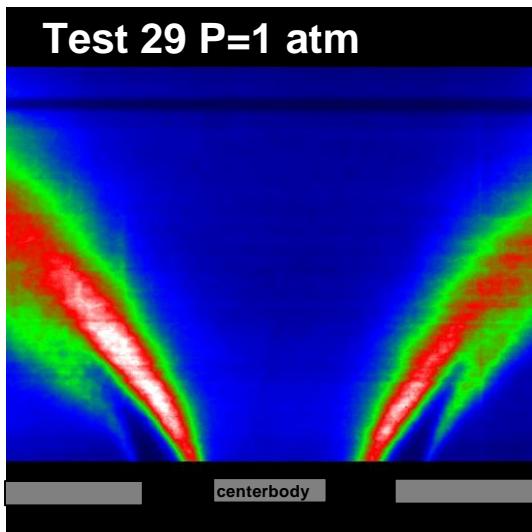
$P=1\text{ atm}$   
Scaled  
0-20,000  
test29



$P=8\text{ atm}$   
(50% H<sub>2</sub>)  
Scaled  
0-5,000  
test33

- Increasing pressure results in thinner flamefront.
  - Consistent with theory and laminar flame calculations.

# Effect of Pressure (Average Images)



60% H<sub>2</sub> / 40% NG  
 $\Phi=0.6$   
 $T_{in}= 522-580K$   
 $V=40 \text{ m/s}$

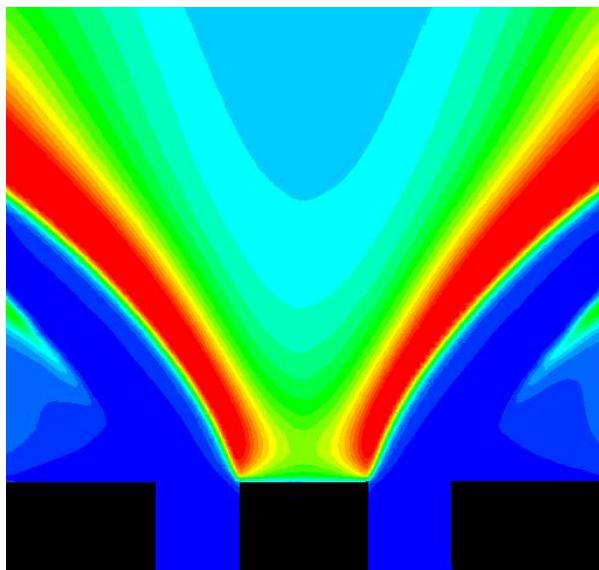
- Average of 200 shots
- Scaled 0-15,000

- OH signal drops off with increasing pressure due to collisional quenching as well as chemistry effects.
  - OH signal  $\sim P^{-1}$

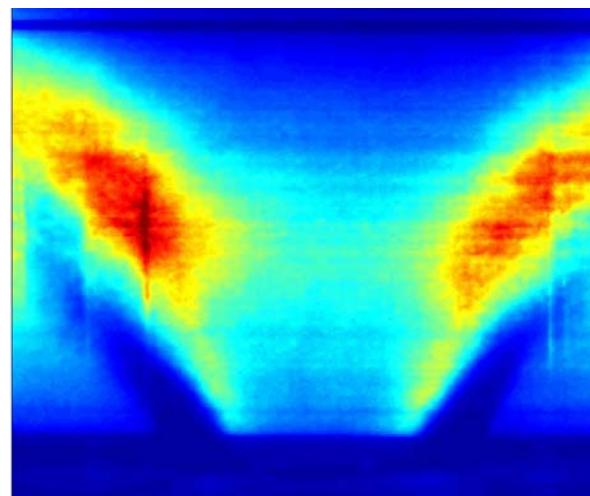
# Example of Model Validation

- *FLUENT 1.1 M Grid Cells, ARM9 Mechanism*
- *EDC Comb Model*
- *RANS - ke model*
- *LES - LDKM Subgrid Stress Model*
- *DO WSGG Radiation Model*

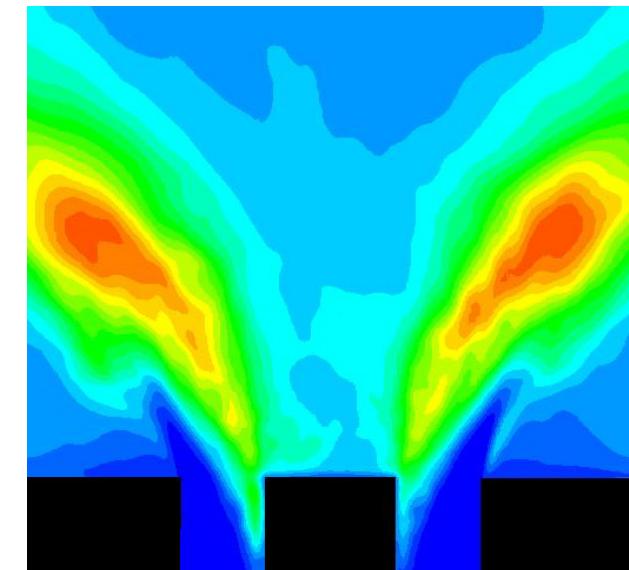
**RANS (OH)**



**Experiment (Average OH)**



**LES (Average OH)**



P=1 atm,  $\phi=0.6$ , H<sub>2</sub>=0%  
OH PLIF: Test25  
Corrected for Attenuation

- LES produces a much more realistic OH field and captures flameholding upstream of dump plane.

# Current and Future SimVal Work

- Repeat OH PLIF measurements to make more quantitative.
- PIV under high-pressure combusting conditions.
- NOx measurements with high H<sub>2</sub> fuel.
- Map out flashback envelope with high H<sub>2</sub> fuel.
- Raman temperature/species measurements.

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